SPECIFICATION

Electronic Version 1.2.8

Stylesheet Version 1.0

Method For The Extraction of Image Features Caused by Structure Light Using Template Information

Background of Invention

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[0001] The present invention relates to a system for observing objects in three dimensional space using structured light. More particularly, the invention relates to a multi-camera, three dimensional sensing system for providing non-contact gauge measurements of an object using known object templates and known epi-polar geometry to identify observable projections of structured light on the surface of an object, and to reconstruct corrupted portions of the projected structured light. The resulting set of data points is then compared with a set of predetermined ideal shape information data points, or a reference model, to identify gauge measurements of the object.

[0002] Measurement systems such as laser range finders, illuminate an object undergoing measurement using structured light. Reflections of the structured light projected on the surface of the object are captured by two or more calibrated cameras, generating images of the illuminated portions of the object's surface. In some applications, the structured light is in the form of a set of laser planes. Where the laser planes intersect the surface of the object, a striping effect is achieved. By detecting these laser light stripes in the images of the object's surface, point correspondences can be established and triangulation techniques employed to reconstruct a representation of the surface of the object.

[0003]

First, a single pixel of each stripe in an images from a first camera is selected.

Given that the position of the first camera lens in space is known and the selected pixel is known, then it is known that the point corresponding to the selected pixel lies on a known line drawn from the lens center out into space. This line appears as a line in an image from a second camera. This line is called the epi-polar line of the selected point in the first image. Since the position of the lens center of the second camera is also known, this epi-polar line can be calculated and drawn in the second image. The epi-polar line, when drawn in the second image, will intersect at least one, and most likely several, of the stripes of the second video image. It is known that one of the pixels where the epi-polar line and a stripe intersect represents the selected point in the first image. The actual coordinate location in space of the point corresponding to any of these intersection points is determined by simple triangulation. Since the position in space of each plane of light which created the stripes is also known, the single point of all the intersection points which correspond to the selected point in the first image is ascertained by determining the three-dimensional coordinate of each intersection point to determine if it lies on one of the known planes of light. The intersection point which lies closest to a known plane of light is taken as the selected point.

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[0004] The surface of many objects includes regions which are shiny or have otherwise poor reflectivity characteristics. Structured light projected onto these surfaces can result in multiple reflections or clutter which, in turn, results in poor laser stripe identification in the resulting images obtained by the cameras. Furthermore, in some situations, entire image regions which are representative of portions of an objects surface may become corrupted due to noise or interference.

[0005] Accordingly, there is a need for a method to enhance laser stripe identification in images, and for a method of reconstructing laser stripes in those portions of images which are heavily corrupted due to noise or interference.

Summary of Invention

[0006] Briefly stated, the present invention sets forth a method for generating a template guide representative of the surface of an object, and for utilizing the template guide to improve laser stripe signal to noise ratios and to compensate for corrupted image regions, thereby improving the accuracy of current laser range finding and

measurement systems.

[0007] The foregoing and other objects, features, and advantages of the invention as well as presently preferred embodiments thereof will become more apparent from the reading of the following description in connection with the accompanying drawings.

Brief Description of Drawings

[0008] In the accompanying drawings which form part of the specification:

[0009] Figure 1 is a simplified view of a image of laser stripes projected on a surface of an object, including both coherent and corrupted regions;

[0010] Figure 2 is a simplified diagram of a tangential flow field for a portion of the image shown in Fig. 1;

[0011] Figure 3 is a simplified diagram of a perpendicular flow field for a portion of the image shown in Fig. 1;

[0012] Figure 4 is a simplified view of a single laser stripe from an uncorrupted image region;

[0013] Figure 5 is a simplified view of a single laser stripe from a corrupted image region; and

[0014] Figure 6 is a collection of three images of a single laser stripe projected on a surface of an object, as seen from three individual cameras.

[0015] Corresponding reference numerals indicate corresponding parts throughout the several figures of the drawings.

Detailed Description

[0016] The following detailed description illustrates the invention by way of example and not by way of limitation. The description clearly enables one skilled in the art to make and use the invention, describes several embodiments, adaptations, variations, alternatives, and uses of the invention, including what is presently believed to be the best mode of carrying out the invention.

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[0017] If repeated measurements of objects of the same type are performed, a set of canonical images can be generated so that the laser stripes in each image can be identified manually. This process results in a set of templates which are representative of the surface of similar objects. Subsequent scans of similar objects will have similar laser striping patterns, with any deviations due to variations in the object surface morphology. The template structures represent prior knowledge of the surface of the objects, such that features in subsequent images which are inconsistent with the expected results, as represented by the templates, can be ignored or de-emphasized.

[0018] Templates can be used in various ways to increase the fidelity of the laser stripe localization process. By using the templates as a guide, a two-dimensional locally matched filter may be generated for each point in an image 10 of projected laser stripes 12A-12H on the surface of an object 13, such as shown in Figure 1. Next, a flow field is established which defines an orientation for each point in an image. A flow field may be either a tangential flow field, as seen in Figure 2, or a perpendicular flow field, as seen in Figure 3. Each arrow shown in Figs. 2 and 3 represents the assigned flow for a given pixel comprising the image.

[0019] The flow field is generated using the templates by way of an orientation diffusion processes, such as, but not limited to, interpolation methods and relaxation methods. The filtering is done in two passes. In the first pass, each pixel (i,j) in an image 10 is given the value:

$$v(i, j) = \sum_{R} (image(r) \times gaussian(r))$$

where R is a curve which emanates from pixel (i,j) and is always tangential to the flow field, r is a measure of arc length along curve R, and image(r) is the image intensity value for a point on curve R. The gaussian term localizes this one dimensional filter.

[0020] In the second pass, each pixel (i,j) is given the value:

$$t(i, j) = \sum_{P} (v(p) \times gaussian(p))$$

where P is a curve emanating from pixel (i,j) and is always perpendicular to the flow field, and p is a measure of arc length along curve P. The result of this two pass approach is a two-dimensional local matched filter responsive to the original image

10. The matched filtering enhances much of the true signal while suppressing unwanted noise.

[0021] Once an image 10 has been processed with the filters, non-maximal suppression techniques are utilized to identify the center of each laser stripe 12A-12H. In one embodiment, each raster line in an image 10 is scanned to identify points where t(i,j) is a local maximum with respect to the raster line. These points represent the detected laser stripe structure. In this way, the laser stripe signal to noise ratio is increased, resulting in an increase in measurement accuracy.

[0022] Alternatively, a single pass approach could also be used by employing a single two-dimensional filter. Or, separable one-dimensional filters which are non-gaussian could also be employed within the scope of the invention.

[0023] Due to problems associated with reflections and laser specularity, a region or laser stripe in image 10 may become corrupted. For example, as seen in Figure 1, laser stripe 12E is corrupted and discontinuous. To determine if a local region of an image 10 is corrupted by either reflections or laser specularity, pixels (i,j) of the image 10 which are representative of local maxima, or zero-crossings, are identified. If pixels (i,j) representative of local maxima in a region are in a structured pattern, i.e. form a line or are "chained", such as seen in laser stripes 12A-12D, 12F-12H, and Figure 4, the region is considered to be coherent and not corrupted. Alternatively, if there are no pixels (i,j) representative of local maxima in a region, or if the representative pixels (i,j) do not form a structured pattern, i.e., are incoherent as seen in laser stripe 12E and Figure 5, the region is marked as corrupted.

[0024] Using the generated template structure and known epi-polar geometry, the corresponding laser stripes in non-corrupted regions of the image 10 can be readily identified. Next, as seen in Figure 6, by using triangulation and projection techniques from multiple view of the object 13, the one or more laser stripes such as 12E in the corrupted regions of the image 10 can be synthesized by using corresponding uncorrupted laser lines in different images 14 and 16.

[0025]

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results are obtained. As various changes could be

made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

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